# CTEQ LHC cross section project

# Participants/programs

- All interested CTEQ people + some interested outsiders
  - John Campbell (MCFM)
  - Jeppe Andersen (BFKL-type calculations)
- LO/NLO/PS/resum
  - Madgraph (could be Alpgen as well but Steve is more familiar with Madgraph)
  - Pythia/Herwig (often in combination with Madgraph)
  - MCFM (can give both LO and NLO predictions)
  - MC@NLO (to test impact of NLO with parton showers, for a limited number of processes)
  - ResBos/wttot
  - …your program

# LHC environment: UE and min bias

- UE tunes and uncertainties (for several of the parton shower Monte Carlos)
  - charged particle multiplicities, transverse momenta
  - jet production from min bias events
  - intrinsic $k_T$ needed for Monte Carlos for various processes
  - impact on min bias events and on UE for hard scattering events

# LHC environment: LO/NLO/NNLO/NNLL

- In the form of *mini-essays*
- What LHC cross sections do we know at NLO/NNLO?
- What cross sections need to be calculated/can be estimated?

- Where do logs come from?
- When do they need to be re-summed? What logs? When soft and when soft+collinear?
- What is the connection between the re-summed logs and the higher order? Is re-summing always a *good thing*? Can scale dependence at NNLO be smaller than scale dependence at (threshold) resummed NLO?
- What is the connection between parton showering and resummation? Parton showering and NLO?
- When may the BFKL-type logs become important?
- When do EW corrections become important?

# LHC environment: pdf's

- Impact of heavy quark mass effects on CTEQ6.6 pdf's
- Uncertainties on and correlations among pdf's
- Pdf luminosities and uncertainties
- Pdf uncertainties for each specific process

# K-factors

- Useful to collect K-factors for available processes (such as from table from review paper with Campbell and Stirling)
  - will update in near future
- Generalizations
  - processes with large color annihilation tend to have large K-factors (gg->H, gg->$\gamma\gamma$)
  - the more final state particles in a process, the smaller the NLO corrections



**Table 1.** $K$-factors for various processes at the Tevatron and the LHC calculated using a selection of input parameters. In all cases, the CTEQ6M pdf set is used at NLO. $\mathcal{K}$ uses the CTEQ6L1 set at leading order, whilst $\mathcal{K}'$ uses the same set, CTEQ6M, as at NLO. Jets satisfy the requirements $p_T > 15\,\text{GeV}$ and $|\eta| < 2.5$ (5.0) at the Tevatron (LHC). In the $W + 2$ jet process the jets are separated by $\Delta R > 0.52$, whilst the weak boson fusion (WBF) calculations are performed for a Higgs boson of mass 120 GeV. Both renormalization and factorization scales are equal to the scale indicated.

| | Typical scales | | Tevatron $K$-factor | | | LHC $K$-factor | | |
|---|---|---|---|---|---|---|---|---|
| Process | $\mu_0$ | $\mu_1$ | $\mathcal{K}(\mu_0)$ | $\mathcal{K}(\mu_1)$ | $\mathcal{K}'(\mu_0)$ | $\mathcal{K}(\mu_0)$ | $\mathcal{K}(\mu_1)$ | $\mathcal{K}'(\mu_0)$ |
| $W$ | $m_W$ | $2m_W$ | 1.33 | 1.31 | 1.21 | 1.15 | 1.05 | 1.15 |
| $W + 1$ jet | $m_W$ | $\langle p_T^{\text{jet}} \rangle$ | 1.42 | 1.20 | 1.43 | 1.21 | 1.32 | 1.42 |
| $W + 2$ jets | $m_W$ | $\langle p_T^{\text{jet}} \rangle$ | 1.16 | 0.91 | 1.29 | 0.89 | 0.88 | 1.10 |
| $t\bar{t}$ | $m_t$ | $2m_t$ | 1.08 | 1.31 | 1.24 | 1.40 | 1.59 | 1.48 |
| $b\bar{b}$ | $m_b$ | $2m_b$ | 1.20 | 1.21 | 2.10 | 0.98 | 0.84 | 2.51 |
| Higgs via WBF | $m_H$ | $\langle p_T^{\text{jet}} \rangle$ | 1.07 | 0.97 | 1.07 | 1.23 | 1.34 | 1.09 |

# Standard Candles

- W/Z
  - inclusive
  - y distribution
    - -5 to +5 in 0.2 bins
  - $p_T$ distribution
    - 0-100 GeV/c in 1 GeV/c bins
    - 0-1 TeV/c in 10 GeV/c bins

- LO
- NLO
  - differences between common programs (MCFM,wttot,ResBos,…)
- NNLO
- Re-summed (ResBos)
- Threshold?
  - connection between NLO+threshold and NNLO
- BFKL effects
- EW effects
- Parton shower (Pythia/Herwig, Madgraph+Pythia, MC@NLO)
- Pdf correlations between W+/W-/Z (at LHC and at Tevatron)

# Standard Candles

- Double and triple gauge boson production
  - WW,ZZ,WZ
  - ZZZ,WWZ

- LO
- NLO
  - Frank for ZZZ
  - Dieter for WWZ
- Re-summed (ResBos)
  - WW,ZZ,WZ
- Parton shower (Pythia/Herwig, Madgraph+Pythia, MC@NLO)

# W/Z + jets

- N jet cross section, where N goes up to 6?
- Jet_n $p_T$ distribution
  - $p_T^{min}$=10,20,30,40 GeV/c inclusive
  - require $p_T^{min,jet1}$=100, 500, 1000 GeV/c
- Z + jet balancing
  - for lead jet $p_T$=20,30,40,50,100 GeV/c
  - cuts on additional jets

- LO, NLO (MCFM)
- Pythia, Herwig
- Madgraph+Pythia
- Effects of BFKL dynamics
- Effects of jet algorithms/parameters
- Correlations with inclusive W/Z production

# Inclusive jets

- From 20 GeV/c to 4 TeV/c
- N jet cross section where N goes up to 6
- Jet_n $p_T$ distribution
  - $p_T^{min}$=10,20,30,40 GeV/c inclusive
  - require $p_T^{min,jet1}$=100, 500, 1000 GeV/c
- LO, NLO (EKS, NLOJET++)
- Pythia/Herwig
- Madgraph+Pythia
- Effects of jet algorithms/parameters

# Inclusive photons

- From 20 GeV/c to 1 TeV/c
- N jet cross section where N goes up to 6
- Jet_n $p_T$ distribution
  - $p_T^{min}$=10,20,30,40 GeV/c inclusive
  - require $p_T^{\gamma}$=100, 500, 1000 GeV/c
- $\gamma$ + jet balancing
  - for lead jet $p_T$=20,30,40,50,100 GeV/c
  - cuts on additional jets

- LO, NLO (Owens,Vogelsang)
- resummed
- Pythia/Herwig
- Madgraph+Pythia

# Diphotons

- Diphoton mass, y, $q_T$,$\Delta\phi$; $p_T$ of each photon
- N jet cross section where N goes up to 6
- Jet_n $p_T$ distribution
  - $p_T^{min}$=10,20,30,40 GeV/c inclusive
  - require $m_{\gamma\gamma}$=100, 500, 1000 GeV

- LO, NLO (DIPHOX)
- Resummed (ResBos)
- Pythia/Herwig
- Madgraph+Pythia

# tT

- Total cross section
- y
  - -5 to 5 in 0.2 bins
- $p_T$
  - 0-2 TeV/c in 20 GeV/c bins
- $m_{tT}$
  - 0-5 TeV in 50 GeV bins

- LO, NLO (MCFM), NNLO (approximated)
- Resummed
- Pythia, Herwig
- Madgraph+Pythia
- Pdf correlation with W/Z
- tT as pdf benchmark

# tT + jets

- N jet cross section where N goes up to 3-4
- Jet_n $p_T$ distribution
  - $p_T^{min}$=10,20,30,40 GeV/c inclusive
  - require $p_T^{min,jet1}$=100, 500
- LO (MCFM), NLO (for tTj: Dittmaier et al)
- Pythia, Herwig
- Madgraph+Pythia
- Pdf correlation with W/Z
- Effects of jet algorithms/parameters

# Single top

- Total cross section
- y
  - -5 to 5 in 0.2 bins
- $p_T$
  - 0-2 TeV/c in 20 GeV/c bins
- LO, NLO (MCFM, other codes), NNLO (approximated)
- Resummed
- Pythia, Herwig
- Madgraph+Pythia
- Pdf correlation with W/Z,tT

# (SM) Higgs

- Cross section (inclusive/subprocess) as function of $m_{Higgs}$
  - 120,200,400,500,1000 GeV/c
- y
  - -5 to +5 in 0.2 bins
- $p_T$
  - 0-100 GeV/c in 1 GeV/c bin
  - 0-1000 GeV/c in 10 GeV/c bins

- LO,NLO (MCFM)
- NNLO
- Resummed, threshold + ResBos
- Pythia, Herwig
- Madgraph+Pythia
- Pdf correlations with W/Z, tT

# (SM) Higgs + jets

- Cross section (inclusive/subprocess) as function of $m_{Higgs}$
  - 120,200,400,500,1000 GeV/c
- y
  - -5 to +5 in 0.2 bins
- For n jets, n=1-4
  - $p_T^{min}$=10,20,30,40 GeV/c
  - require $p_T^{min,jet1}$=100, 500

- LO,NLO (MCFM)
- Pythia, Herwig
- Madgraph+Pythia
- Pdf correlations with W/Z, tT
- Effects of jet algorithms/parameters

# BSM Higgs